Hydrological Ensemble Prediction Experiment (HEPEX)

CEA Technologies Inc.

WATER MANAGEMENT PROCESS TO MEET EFFICIENCY, REGULATOR AND ENVIRONMENTAL OBJECTIVES

November 3 - 4, 2004

Vancouver, BC, Canada

User's Group Presentation by

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HEPEX is an independent international organization that is developing affiliations with international, national and other organizations that wish to be affiliated.

Hydrological Ensemble Prediction Experiment (HEPEX)

Value of ensemble weather forecasts

- Improve mid-term inflow forecasts
- Improved targets for short-term operations
- Identify methods for river basins and projects
- Go beyond rule curve operations (more benefit).

HEPEX Goal

- **HEPEX aims to** demonstrate how to produce reliable hydrological ensemble forecasts that can be used with confidence to make decisions for emergency management and water resources management.

This will have important consequences for the economy, for public health and safety.

Hydrological Ensemble Prediction Experiment (HEPEX):

- Application to price forecasting, hydrologic forecasting, and water quality forecasting.
  - Quantify environmental benefits and economic benefits.

Hydrological Ensemble Prediction Experiment (HEPEX):

- Alternative methods of optimization modeling will be evaluated for suitability with ensemble forecasts.
- Applicability to a range of site specific factors could be investigated

Why have Ensemble Weather Forecasts?

Why not use just historical weather?

It’s all about recognizing current conditions……..

Year 1550 to Year

Accumulated deviation from the mean

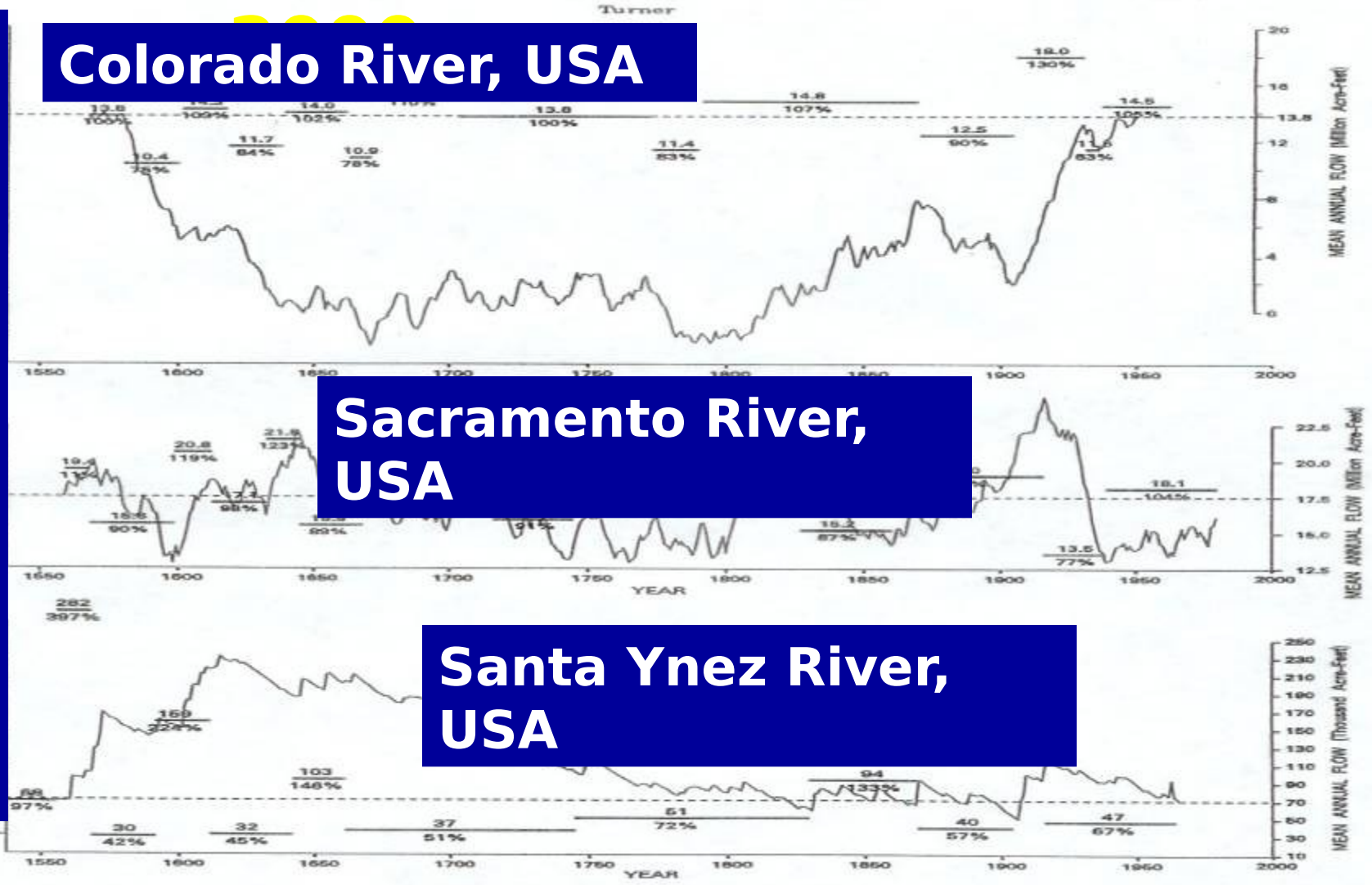
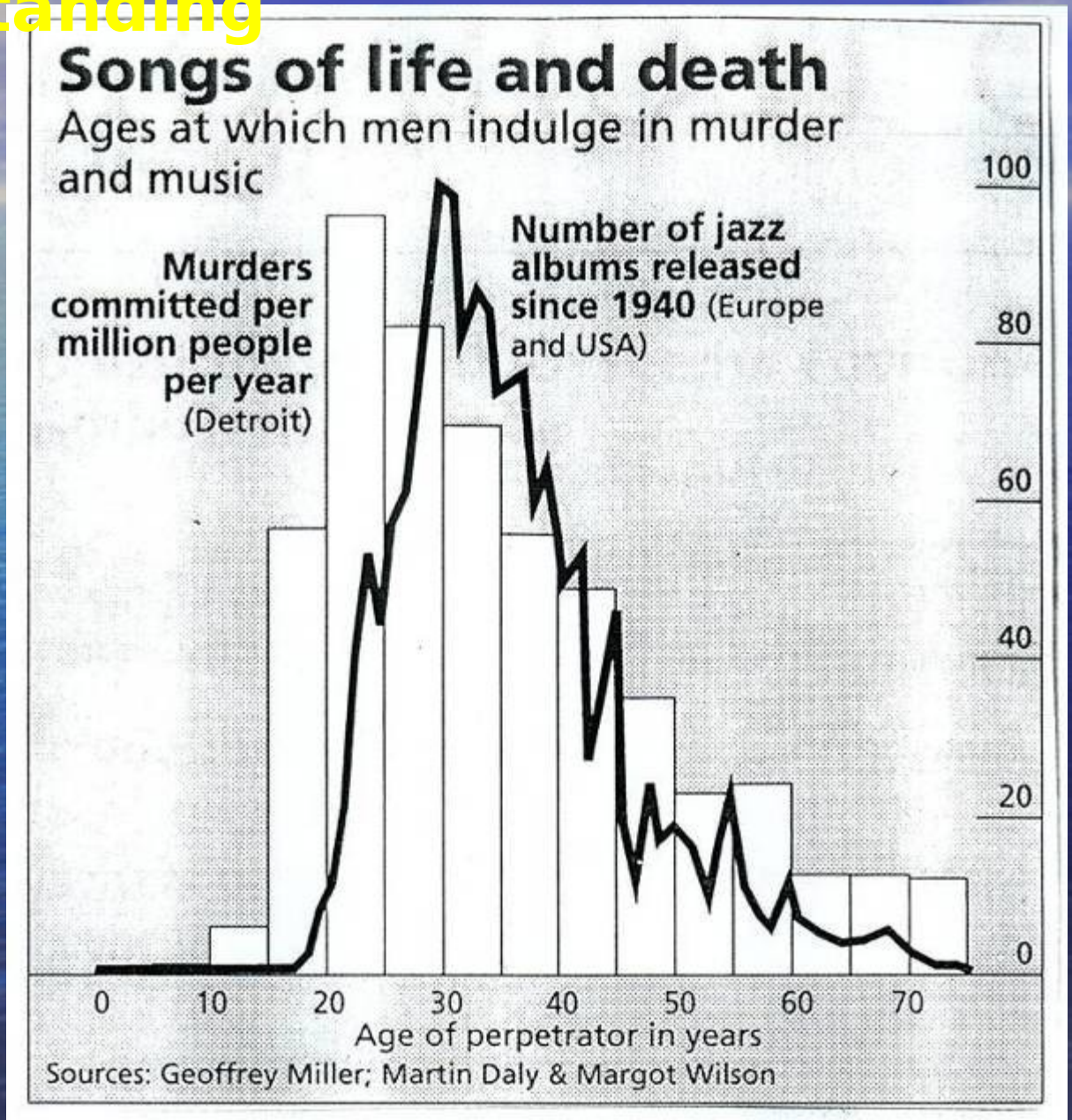


Figure 1. Accumulated Deviation from the Mean and Mean Annual Flows for Generally Wet, Normal, and Dry Periods.

Statistics are blind –need physical understanding



Decision Support System Design and Implementation

Elements of the Decision Support System

- Realistic Reliable Data (RRD)
- Models
- Physically Understandable Outputs
- Trained People

Decision Support Systems

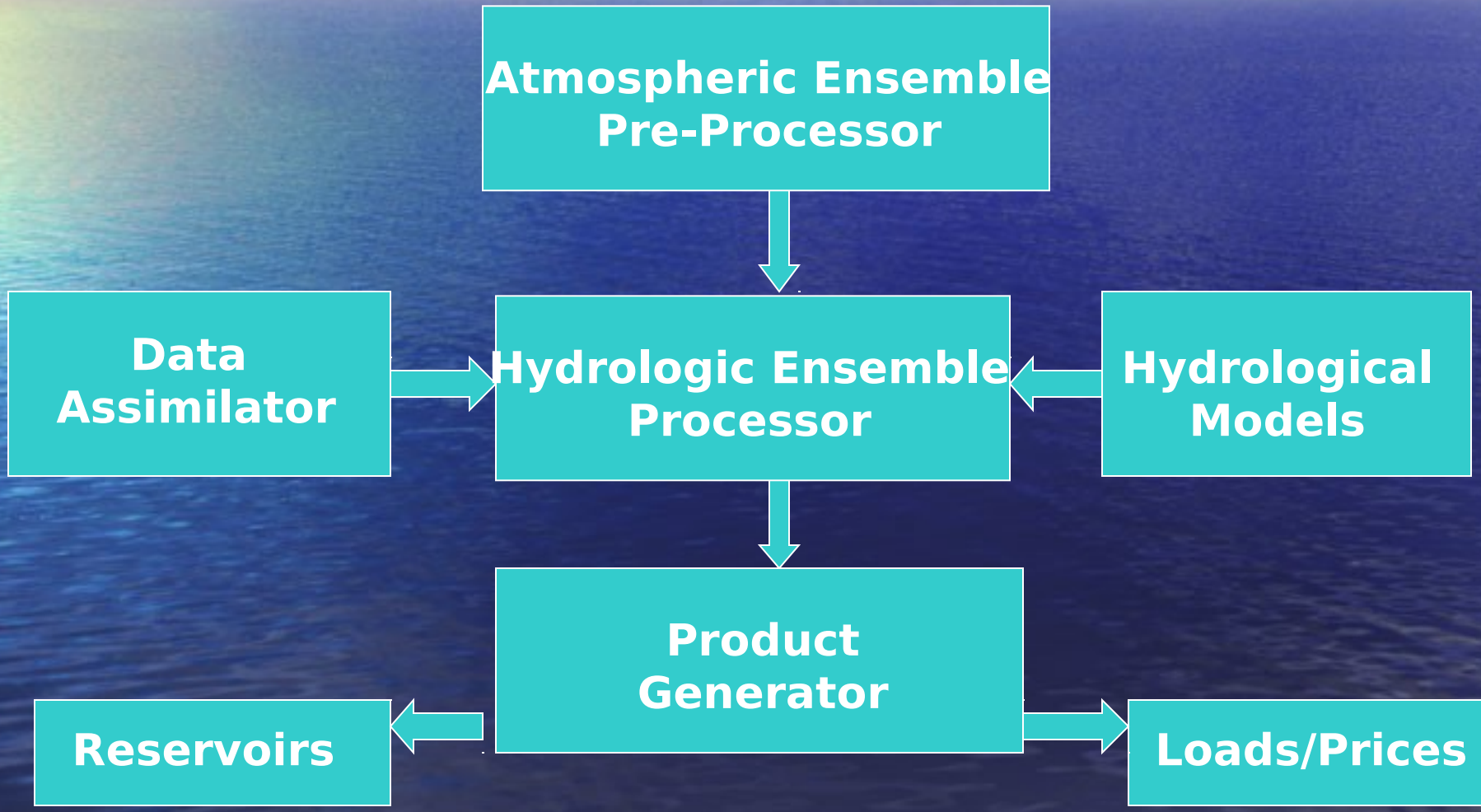
Yesterday:

- studies of historical data.
- decisions based on rules

Today:

- monitoring and current data
- decisions based on optimization

Elements of a Hydroelectric Ensemble Based Prediction System



Optimization Models

Long Term Storage Strategy

- **Conditional Probability - Ensemble Forecasts**
- **Updated Weekly**
- **Weekly Time Step**
- **One Year Time Horizon**
- **Major Reservoirs**

Optimization Models

Short Term Generation Scheduling

- **Complete Power System Model**
- **Power Prices and Loads**
- **Unit Efficiencies**
- **Operating Constraints**
- **River Dynamics**
- **Hourly Time Step**
- **168 Hour Time Horizon**

The Short Term Generation Scheduling Determined Within the Midterm Storage Strategy

Outputs

1. Avoid Environmental Conflicts

- **Manage Floods Objectively**
- **Meet Non-Power Constraints**

2. Optimized Powerplant Operations

- **Meet Load With Minimum Water**

3. Optimized System Operation

- **Meet Load With Minimum Water**
- **Maximize Revenue**

4. Optimized Storage Scheduling

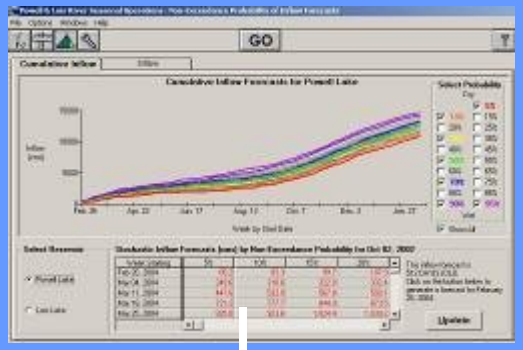
- **Conditional Probability Considered**

The inputs are weekly hydrologic ensemble forecasts and current energy price estimates.

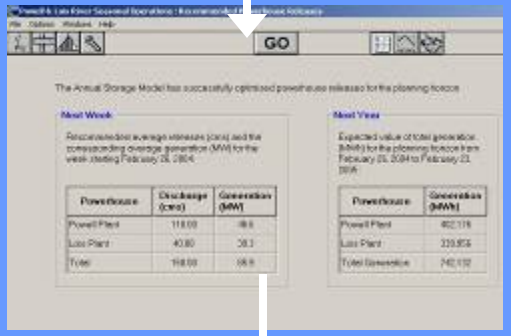
The one year time horizon reservoir operations model is a non-linear optimization.

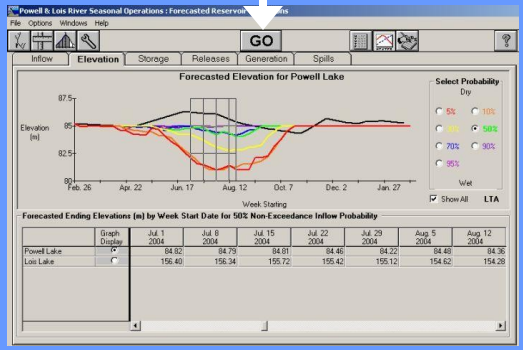
The recommendation is the specific optimum power generation for this week.

The result is the week by week probability distributions for future power and reservoir states.



Objectives and constraints



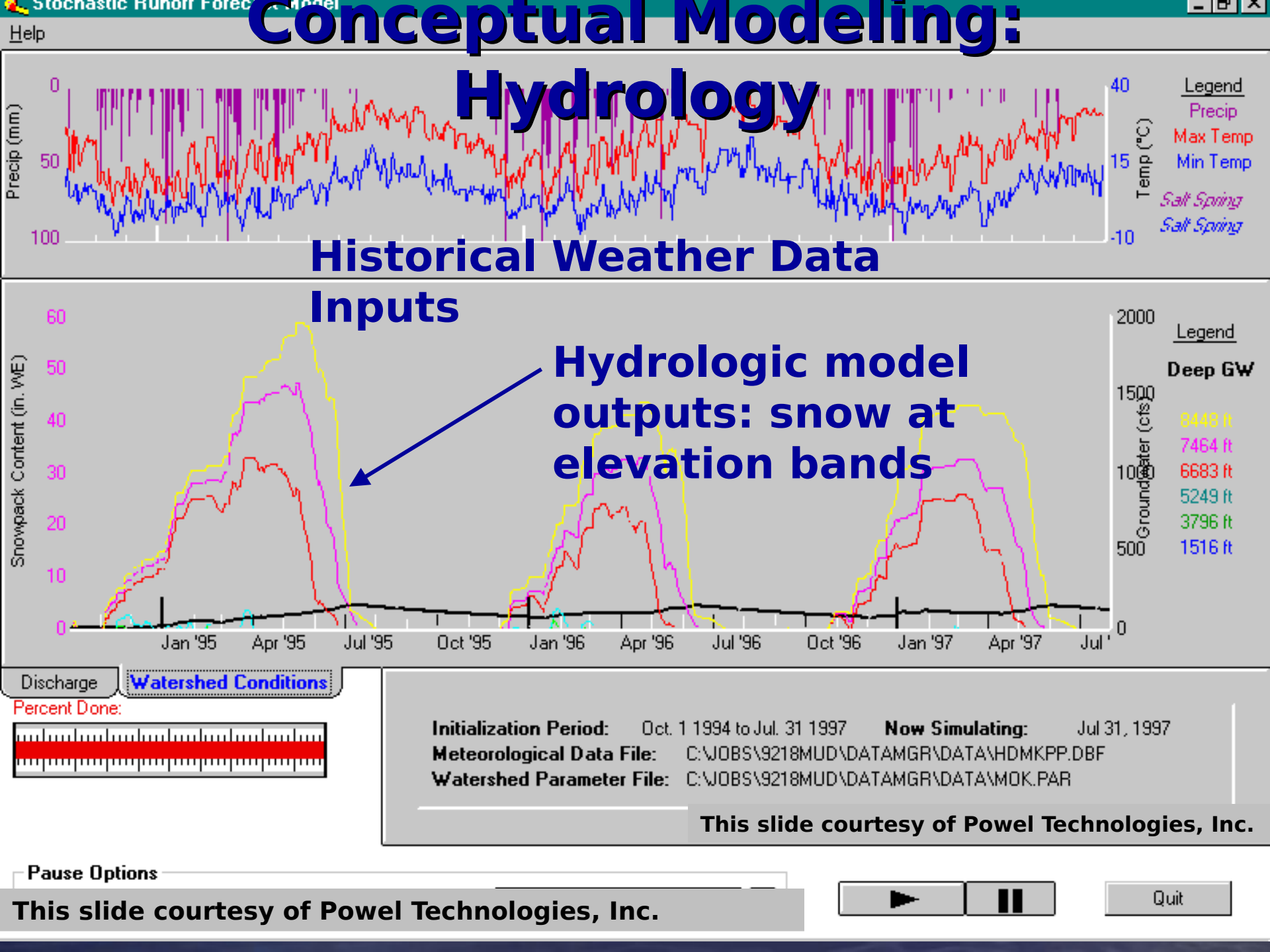


Conditional Inflow Forecasts

- Current watershed state (actual water in natural storage in the basin, lakes, marshes, river channels, snow)

- Possible future weather – HEPEX!

Conceptual Modeling: Hydrology



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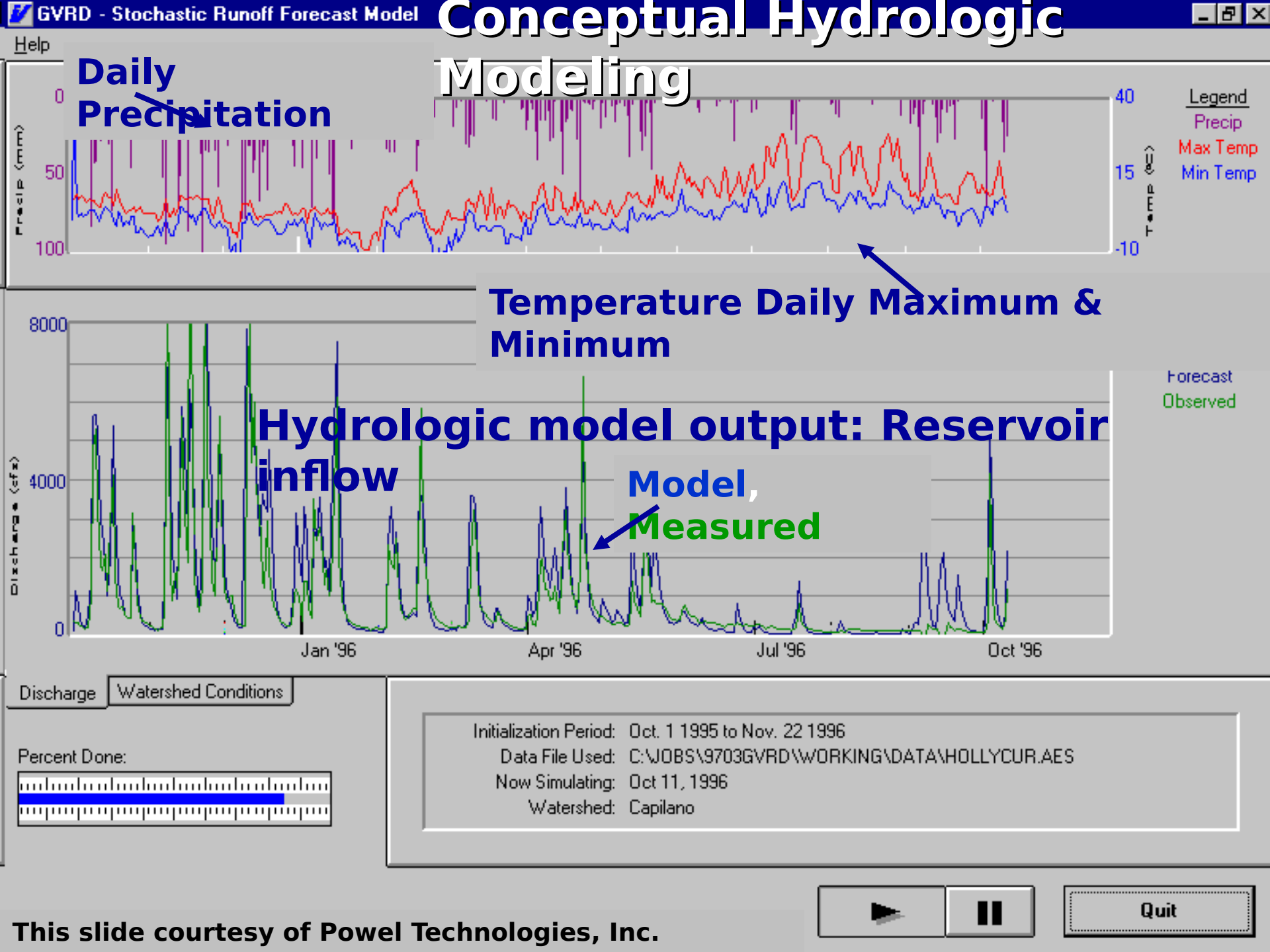

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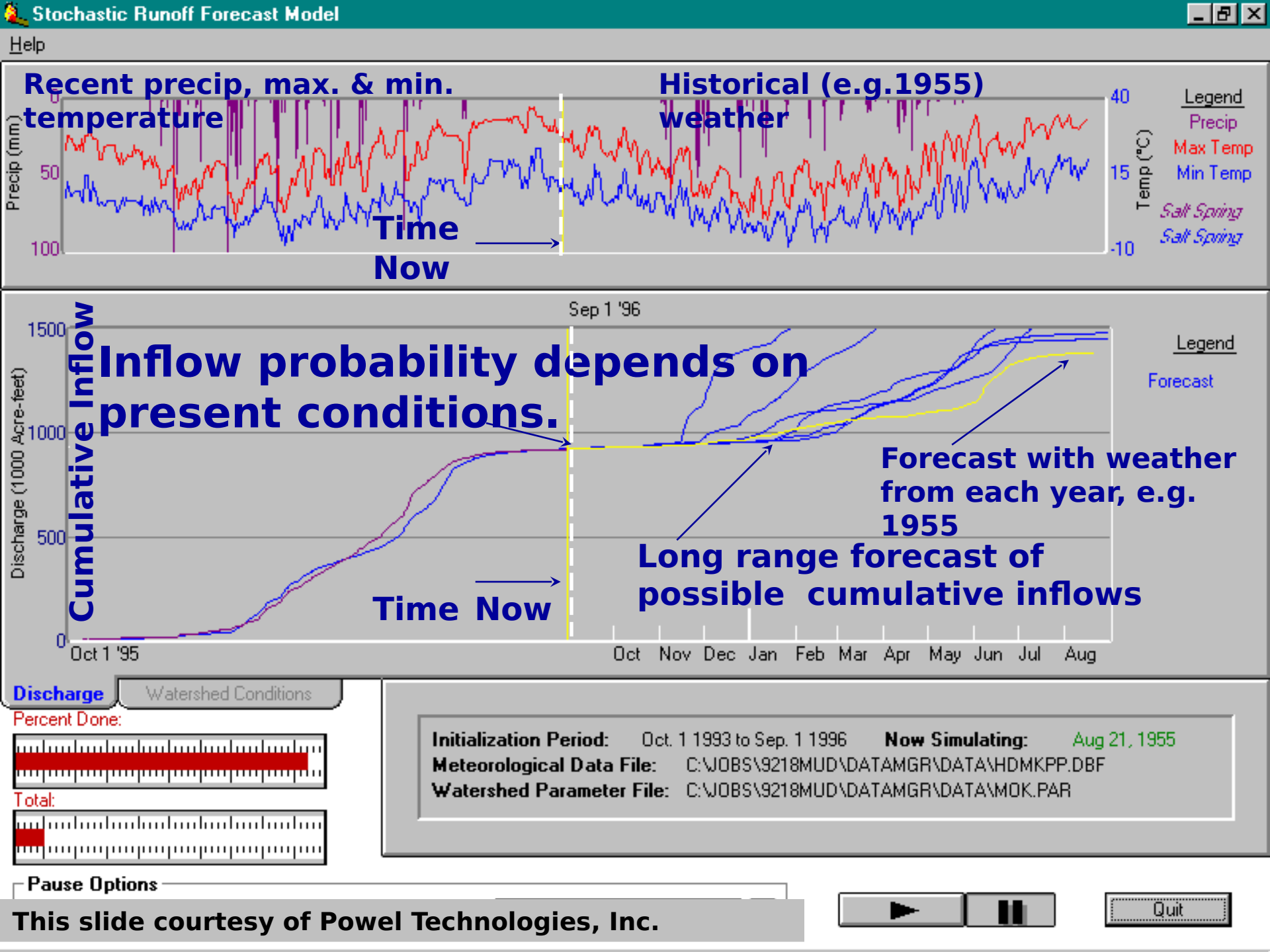
Reservoir Inflow Forecasts

- **Ensemble of historical weather: a sample of possible future weather, but this is not a forecast.**

- **Ensemble weather forecast: potentially better estimate of possible future weather – HEPEX!.**


Stochastic Runoff Forecast Model
Help
Recent precip, max. & min. temperature
Historical (e.g.1955) weather
Time Now
Precip (mm)
Temp (°C)
Legend
Precip
Max Temp
Min Temp
Salt Spring
Salt Spring
Sep 1 '96
Cumulative Inflow
Discharge (1000 Acre-feet)
Inflow probability depends on present conditions.
Time Now
Forecast with weather from each year, e.g. 1955
Long range forecast of possible cumulative inflows
Legend
Forecast
Oct 1 '95
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug
Discharge
Watershed Conditions
Percent Done:
Total:
Initialization Period: Oct. 1 1993 to Sep. 1 1996
Now Simulating: Aug 21, 1955
Meteorological Data File: C:\JOBS\9218MUD\DATAMGR\DATA\HDMKPP.DBF
Watershed Parameter File: C:\JOBS\9218MUD\DATAMGR\DATA\MOK.PAR
Pause Options
Quit
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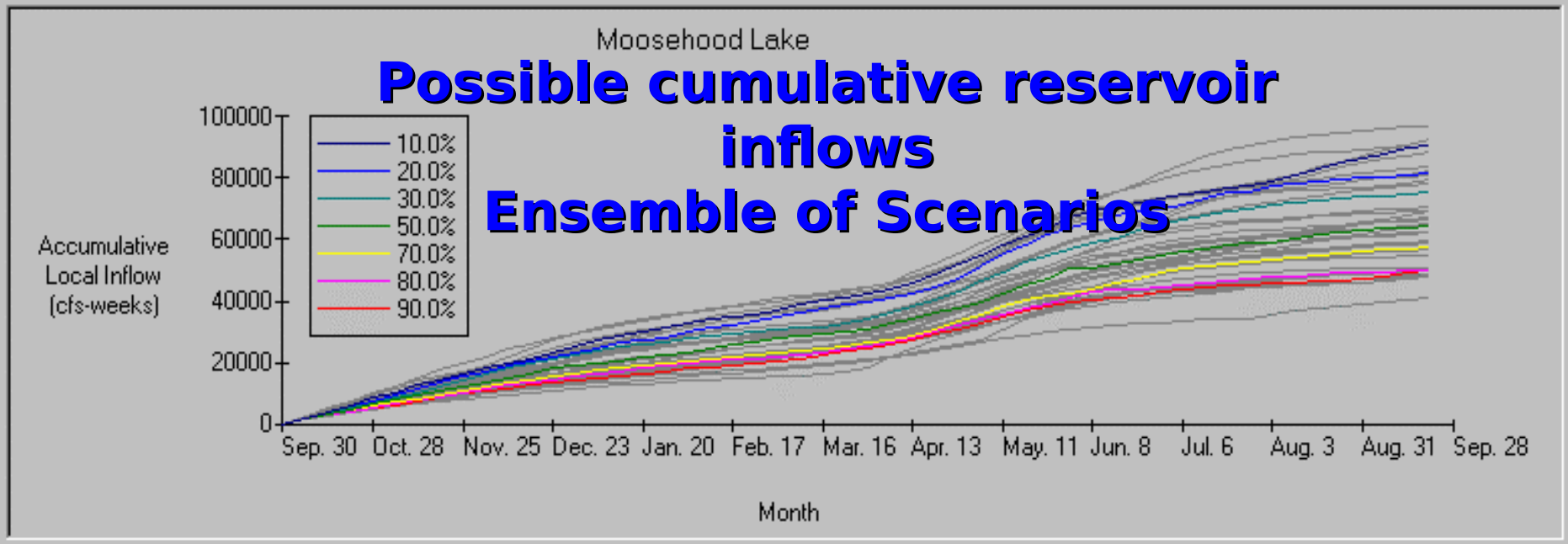
HYDROPS - Seasonal Operations - [Local Inflow Forecast - Cumulative Probability]

File Edit Windows Help

GO



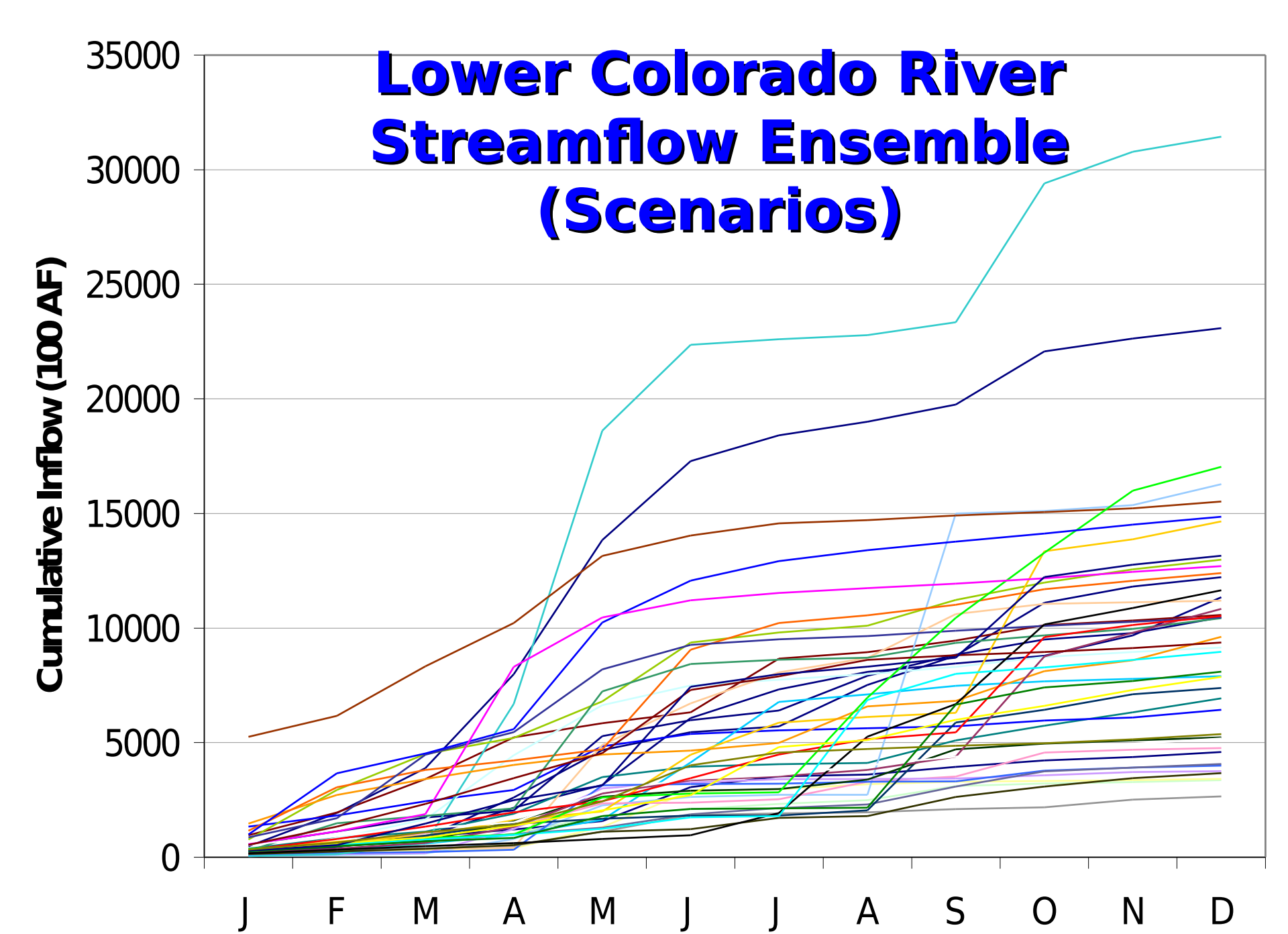
Select Input Node

- Brassun Lake
- (•) Moosehood Lake
- Flagstiff Lake
- Wymen
- Arson
- Westan

Stochastic Inflow Results (cfs-weeks) by Probability Level

Week Start	2.50%	5.00%	7.50%	10.00%	12.50%	15.00%	17.50%
1(Sep. 30, 91)	0	0	0	0	0	0	0
2(Oct. 7, 91)	2846	2590	2474	2269	2247	2133	2124
3(Oct. 14, 91)	5103	4905	4457	4225	4210	4157	4101
4(Oct. 21, 91)	7644	7536	6546	6111	6033	6028	5969
5(Oct. 28, 91)	10398	9678	9169	8520	8197	7893	7715
6(Nov. 4, 91)	12385	12078	11366	10526	10230	10062	9916
7(Nov. 11, 91)	14806	14007	13005	12645	12450	12180	11922

Starting Date: Sep. 30, 1991 Ending Date: Sep. 27, 1992



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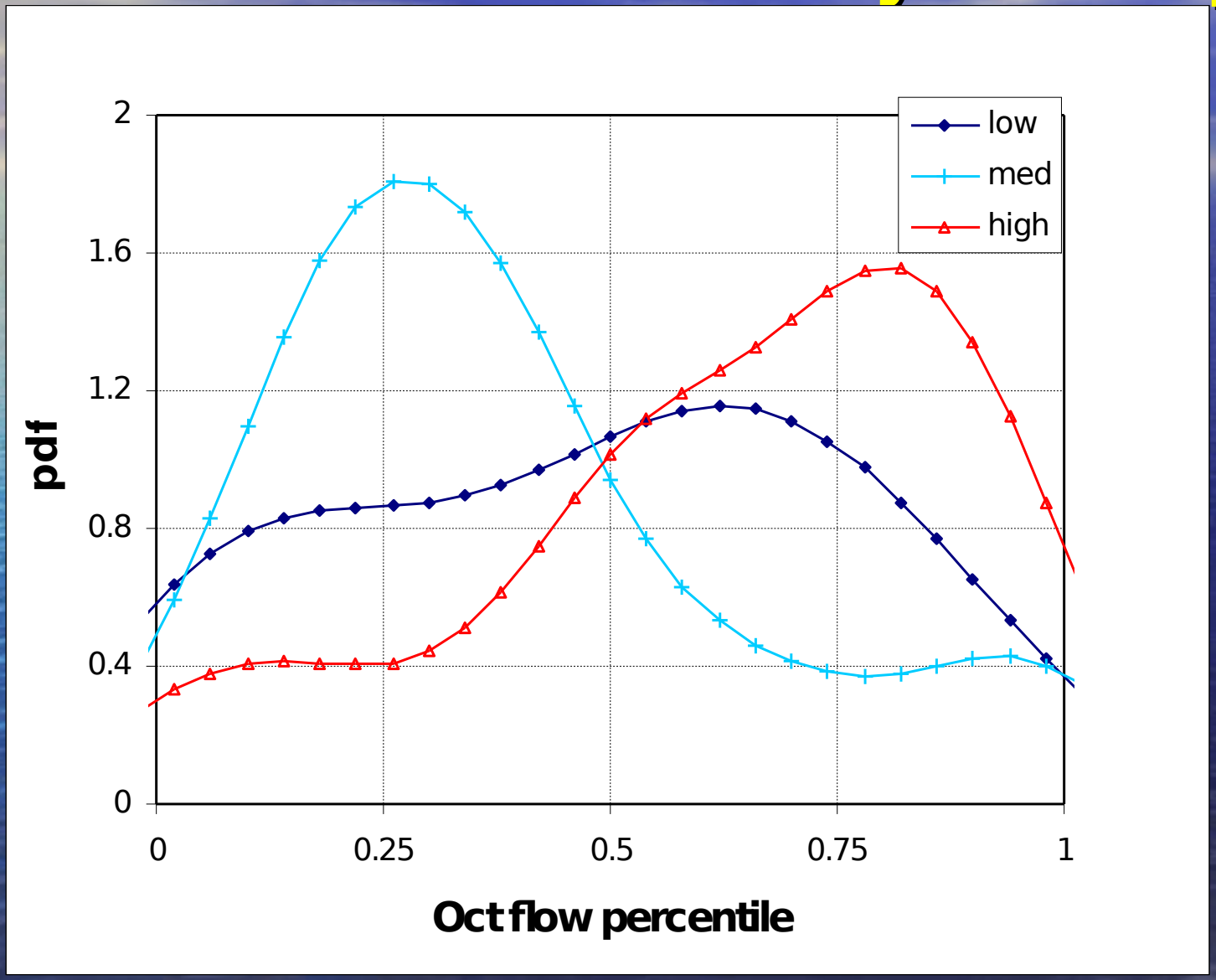
Forecasts
Conditional Probability Density



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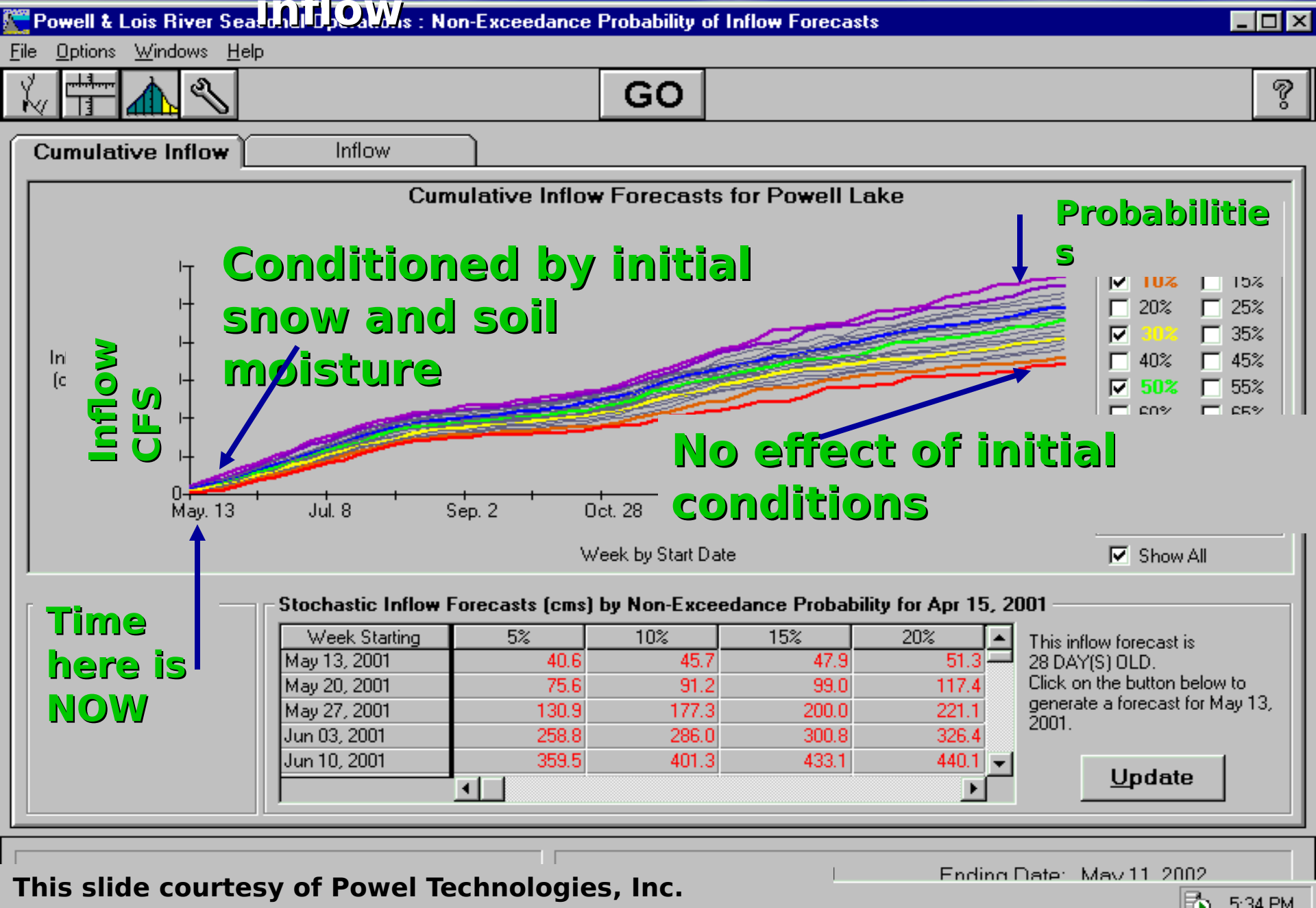
Conditional probability of cumulative inflow


Powell & Lois River Seasonal Operations : Non-Exceedance Probability of Inflow Forecasts
File Options Windows Help
GO
Cumulative Inflow
Inflow
Cumulative Inflow Forecasts for Powell Lake
Probabilities
Conditioned by initial snow and soil moisture
Inflow CFS
No effect of initial conditions
May. 13
Jul. 8
Sep. 2
Oct. 28
Week by Start Date
Show All
Time here is NOW
Stochastic Inflow Forecasts (cms) by Non-Exceedance Probability for Apr 15, 2001
Week Starting | 5% | 10% | 15% | 20%
May 13, 2001 | 40.6 | 45.7 | 47.9 | 51.3
May 20, 2001 | 75.6 | 91.2 | 99.0 | 117.4
May 27, 2001 | 130.9 | 177.3 | 200.0 | 221.1
Jun 03, 2001 | 258.8 | 286.0 | 300.8 | 326.4
Jun 10, 2001 | 359.5 | 401.3 | 433.1 | 440.1
This inflow forecast is 28 DAY(S) OLD.
Click on the button below to generate a forecast for May 13, 2001.
Update
Ending Date: May 11, 2002

This slide courtesy of Powel Technologies, Inc.

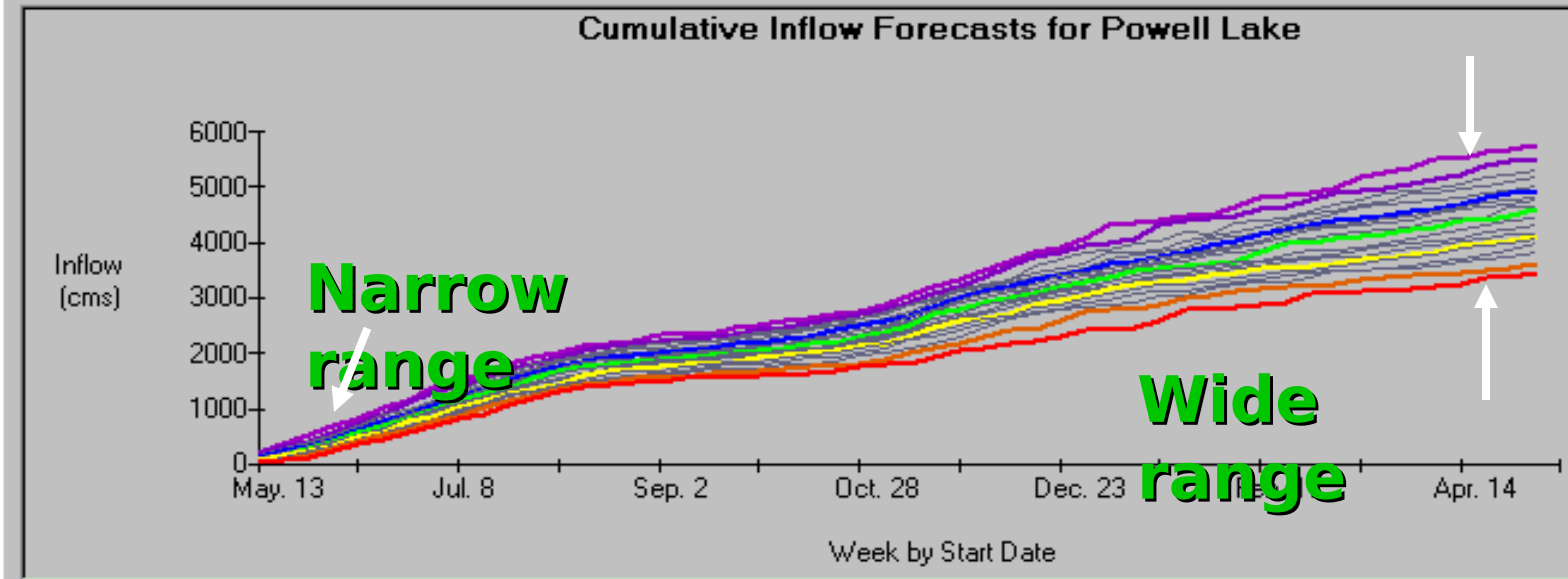
Conditional probability of cumulative inflow

Powell & Lois River Seasonal Operations : Non-Exceedance Probability of Inflow Forecasts

File Options Windows Help

GO

Cumulative Inflow | Inflow



Select Probability

Dry

- [x] 5%
- [x] 10%
- [ ] 15%
- [ ] 20%
- [ ] 25%
- [x] 30%
- [ ] 35%
- [ ] 40%
- [ ] 45%
- [x] 50%
- [ ] 55%
- [ ] 60%
- [ ] 65%
- [x] 70%
- [ ] 75%
- [ ] 80%
- [ ] 85%
- [x] 90%
- [x] 95%

Wet

- [x] Show All

Select Reservoir

- (•) Powell Lake
- ( ) Lois Lake

Stochastic Inflow Forecasts (cms) by Non-Exceedance Probability for Apr 15, 2001

Week Starting	5%	10%	15%	20%
May 13, 2001	40.6	45.7	47.9	51.3
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This inflow forecast is 28 DAY(S) OLD.
Click on the button below to generate a forecast for May 13, 2001.

Update

Charles Howard & Associates Ltd

Starting Date: May 13, 2001 Ending Date: May 11, 2002

Start | Exploring - D:\jobs\9911P | Powell & Lois River S | 5:34 PM

Linear Programming Model

- **Objective function**
  - Irrigation, recreation, and hydropower benefits
  - Penalties for water demand deficits
- **Constraints**
  - Mass balance at reservoirs and diversion points
  - Water supply deficits
  - Seasonal crop water demands
  - Interruptible contract function
  - Diversions limited by contract function
- **Decisions**
  - Interruptible contracts
  - Reservoir releases
  - Area planted

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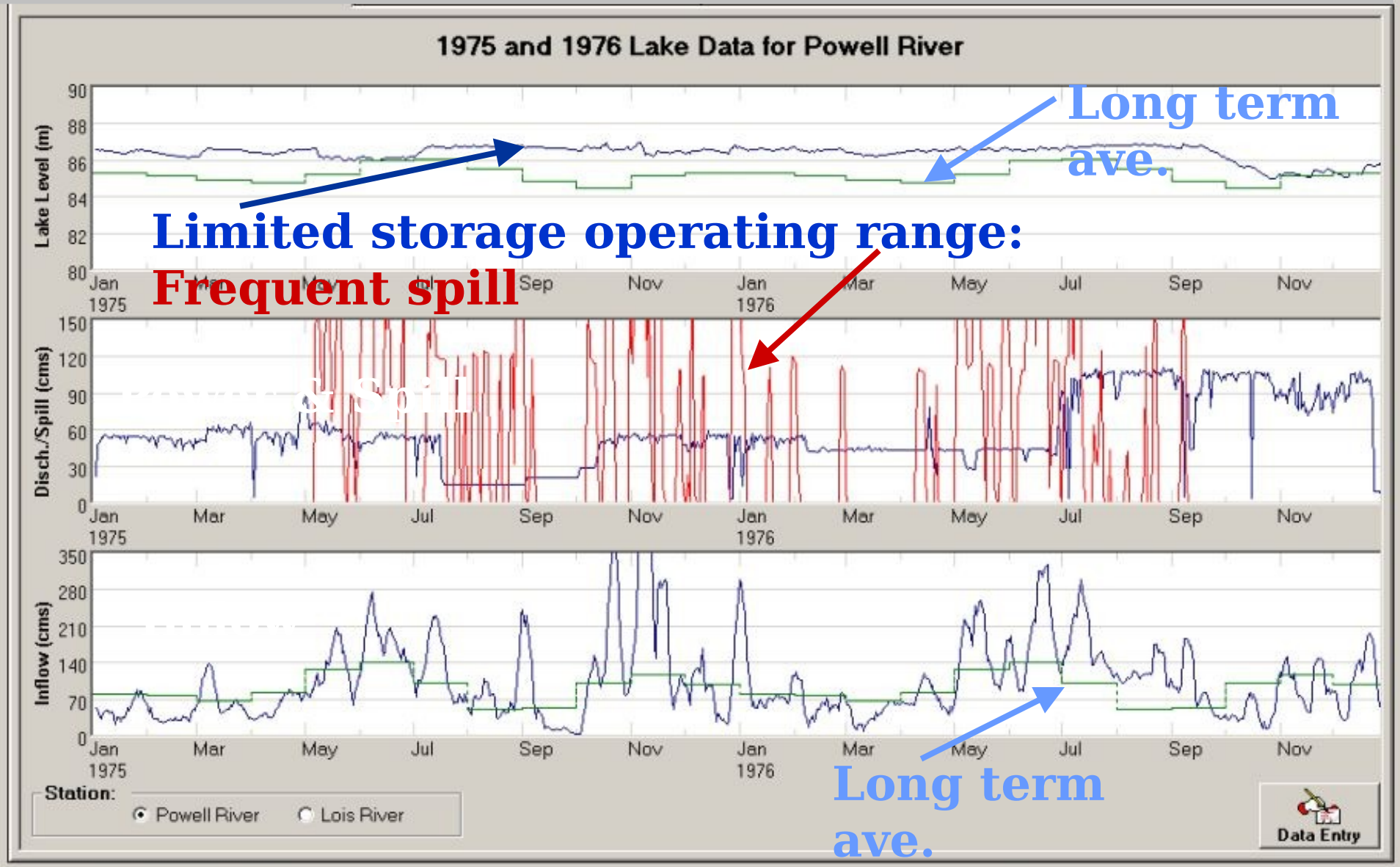
Reliability of minimum generation

Truncate the hydrologic ensemble forecast at an appropriate probability level.

For example, the recommended generation may go to the lower bound (minimum generation) in at least one of the hydrologic sequences provided in the input.

The driest sequence controls the reliability.

Operation Before Ensemble Optimization



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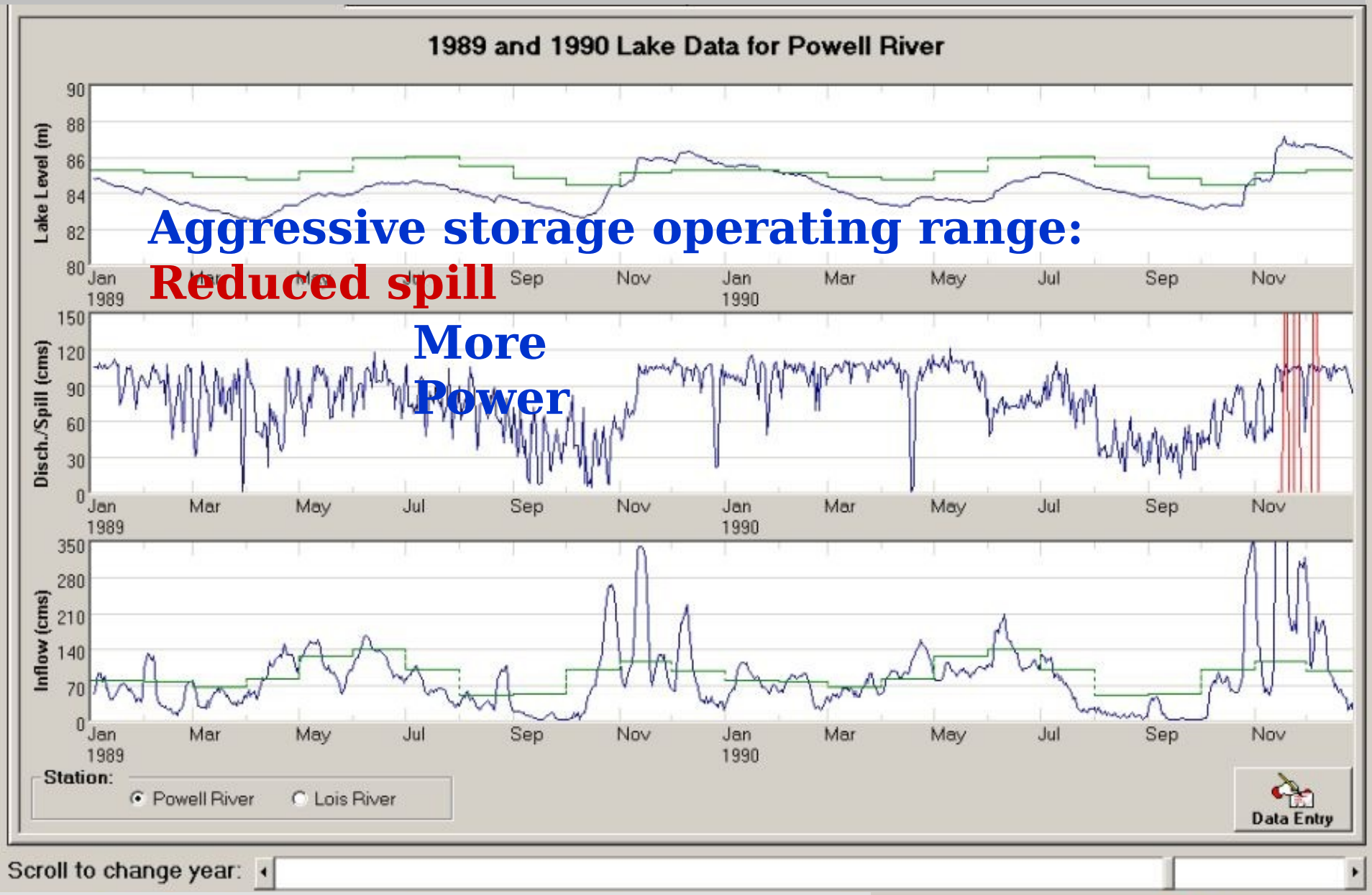
Operation After Ensemble Optimization



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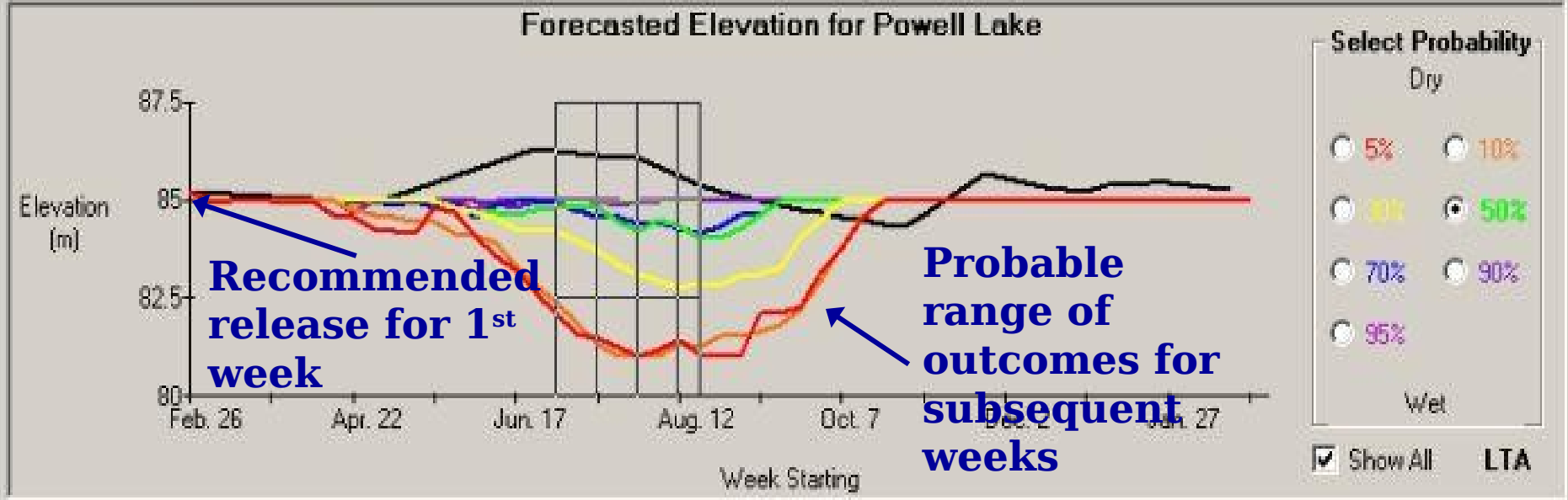
Powell & Lois River Seasonal Operations : Forecasted Reservoir Operations

File Options Windows Help

GO

Inflow | Elevation | Storage | Releases | Generation | Spills



Forecasted Ending Elevations (m) by Week Start Date for 50% Non-Exceedance Inflow Probability

	Graph Display	Jul. 1 2004	Jul. 8 2004	Jul. 15 2004	Jul. 22 2004	Jul. 29 2004	Aug. 5 2004	Aug. 12 2004
Powell Lake	◉	84.82	84.79	84.81	84.46	84.22	84.48	84.36
Lois Lake	○	156.40	156.34	155.72	155.42	155.12	154.62	154.28

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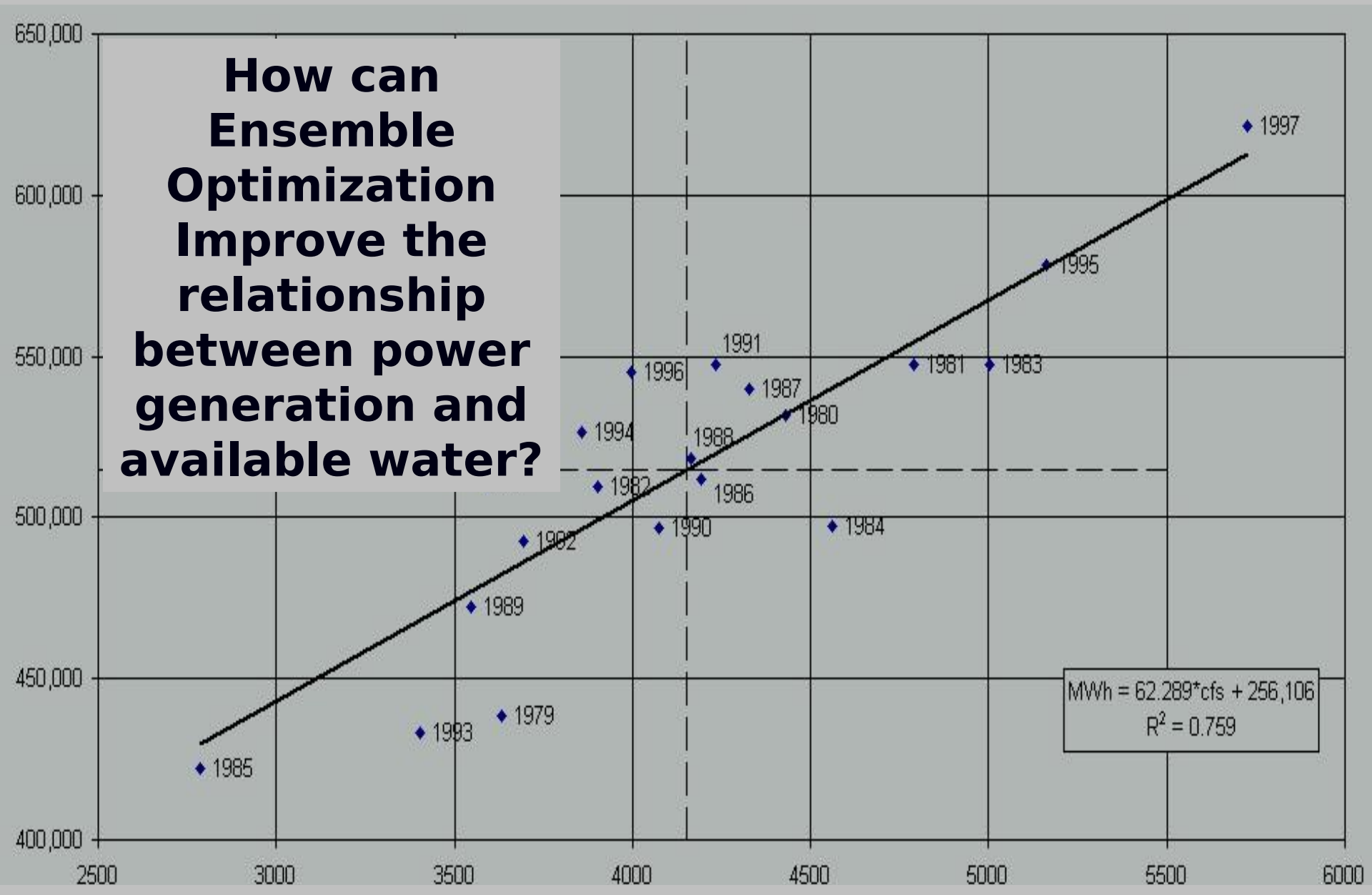
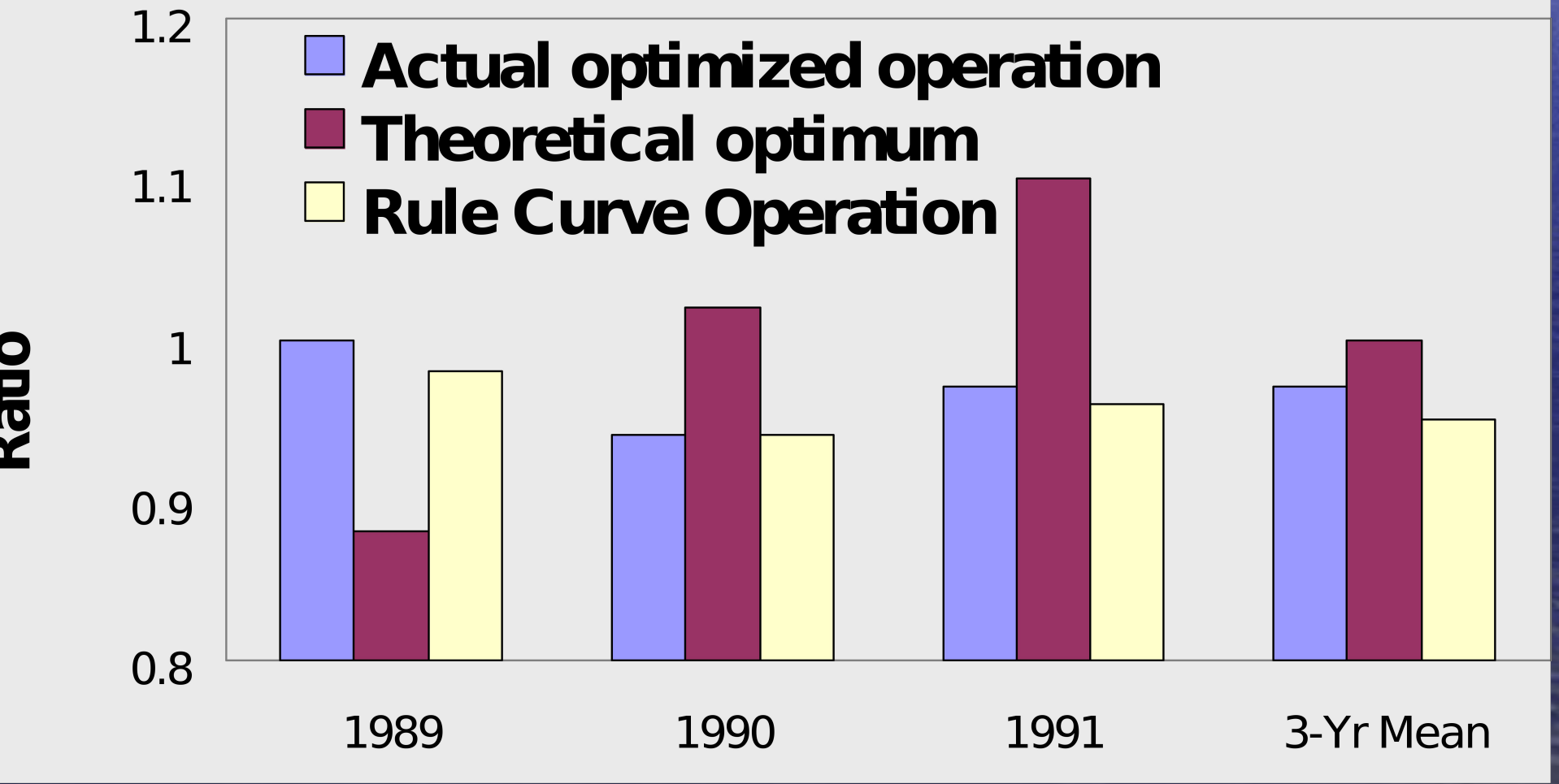
MWH



Average Annual Inflow, CFS

Hydrologic Ensemble Optimization
Powell River Hydroelectric Project, B.C.



Hydrologic Ensemble Optimization
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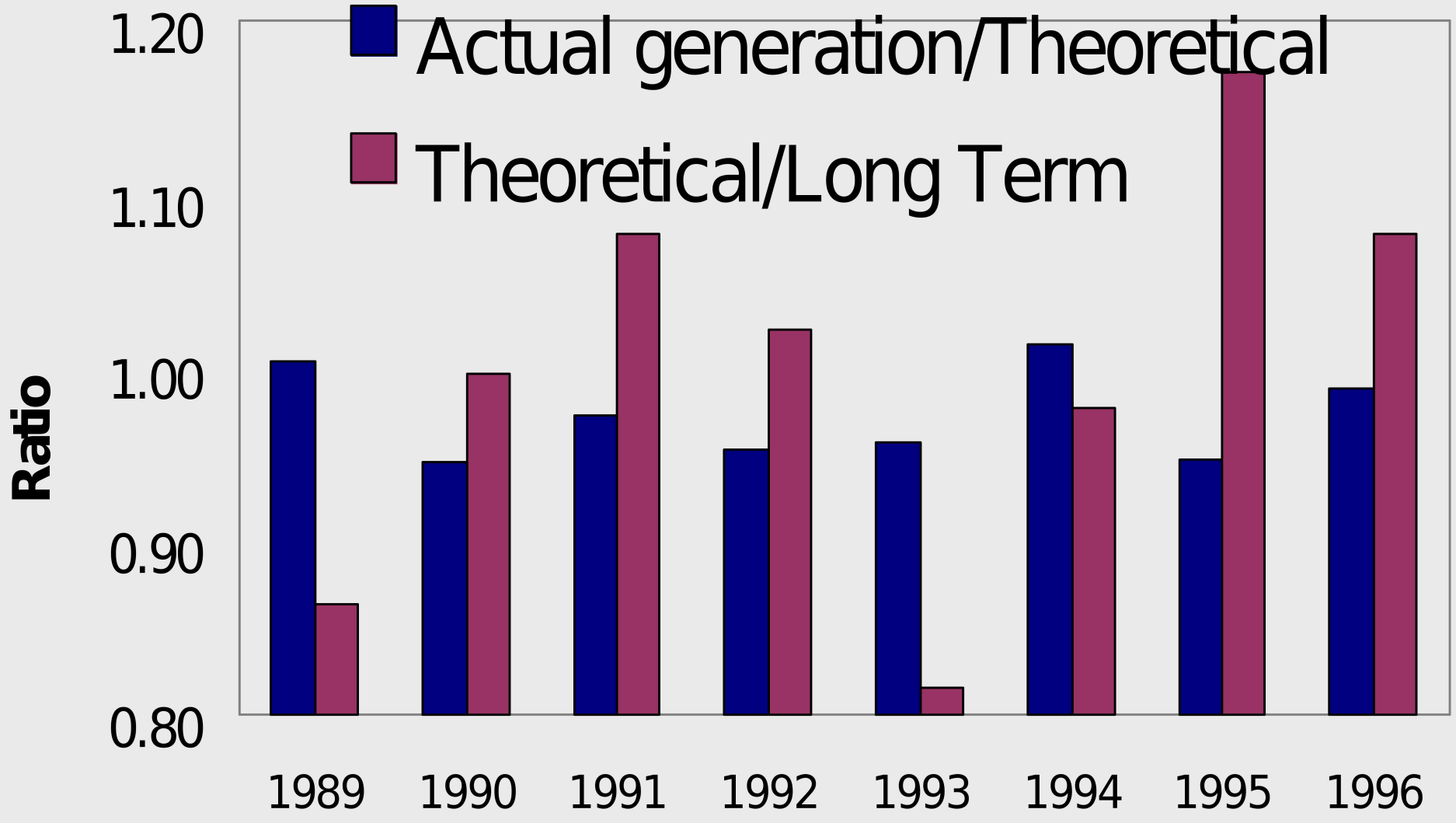
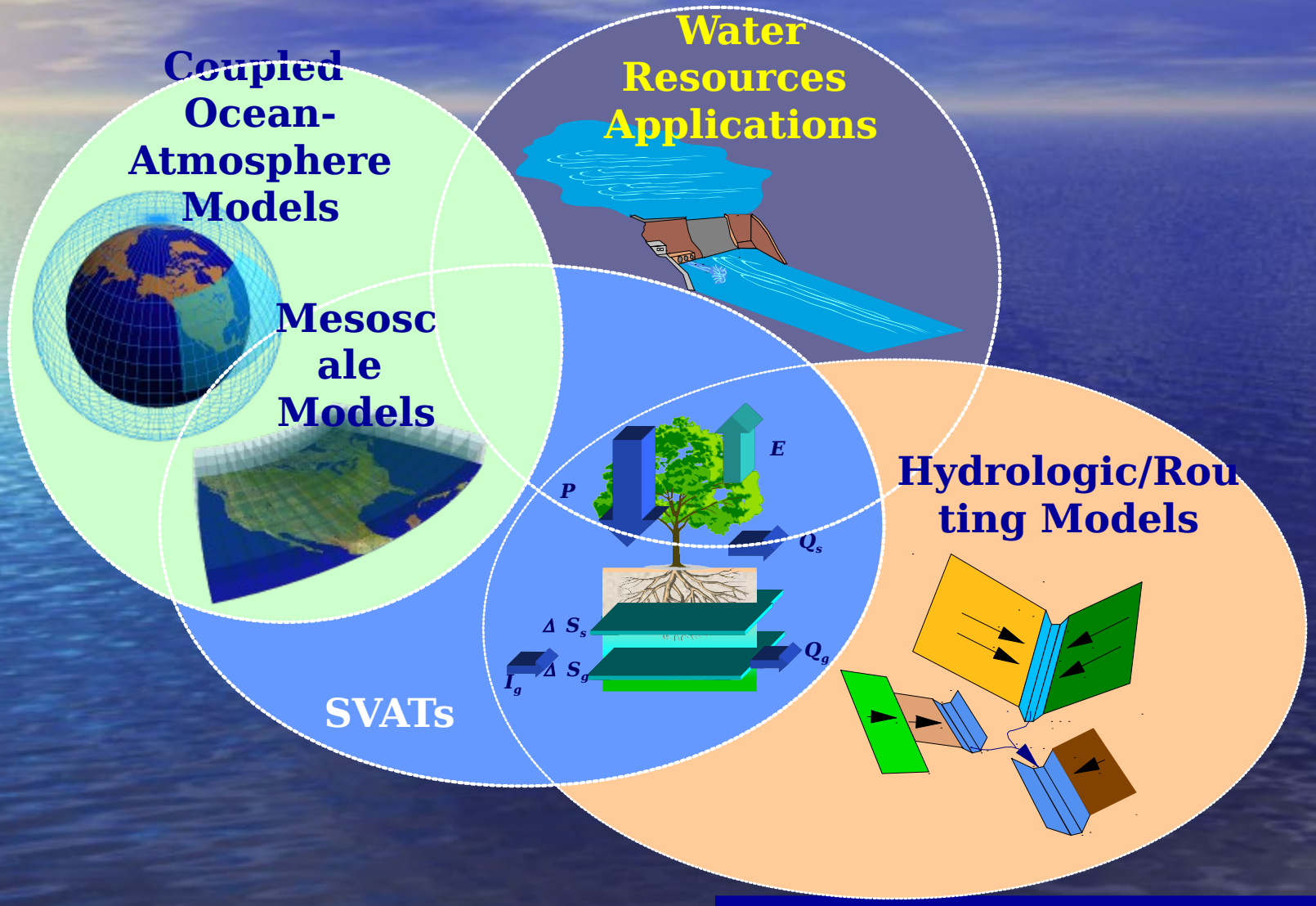


HEPEX Goal

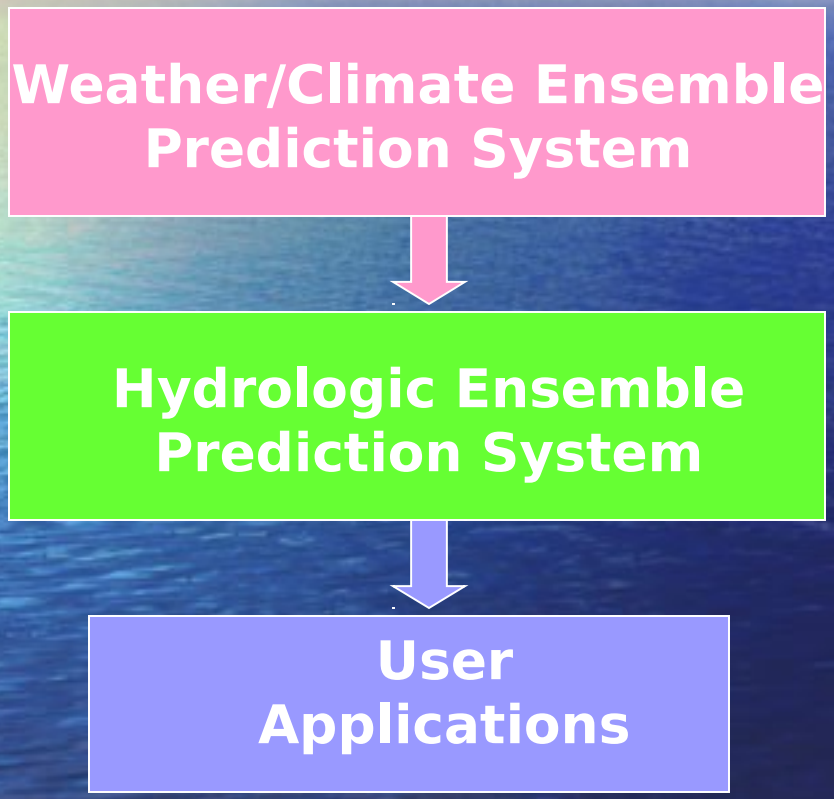
- **HEPEX aims to** demonstrate how to produce reliable hydrological ensemble forecasts that can be used with confidence to make decisions for emergency management and water resources management.

This will have important consequences for the economy, for public health and safety.

Model Coupling, Downscaling, and Hydrologic Applications



HEPEX Basic Building Blocks



- All 3 blocks are emerging
- Major work needed
- Must be done in an integrated way
- Example

Initial Workshop

http://www.ecmwf.in

March 8-10, 2004

- **European Centre Medium Range Weather Forecasting**
- **80 Participants, 16 Countries**

- **Users: NY Power, BC Hydro, Quebec Hydro, EDF (France), Mekorot (Israel), WMIG (Canada), Howard (Canada), SMHI (Sweden), BGF (Germany)**
- **Scientists: Meteorologists, Hydrologists**

Current Status

- W/S report complete (19 page summary)
- Recent Meetings
  - EGU (Nice)
  - Spring AGU (Montreal)
  - UNESCO Workshop (Koblenz)
  - German Pilot Project-Danube (Offenbach)
  - EU Workshop (MUSIC, et al)(Helsinki)
  - GEWEX Executive Committee (Baltimore)
  - HYDROVISION – (August, Montreal)
- Future Meetings
  - CEATI WMIG W/S (Vancouver, November)
  - EU/JRC (Ispra, November)
  - ACTIF Workshop (Delft, November)
  - AGU2004 Fall Hydrologic Ensemble Session (December)
  - IAHS2005 – Iguacu (April)
  - EGU2005 HEPEX Session (April)
- Connection to THORPEX?
  - THORPEX Interactive Grand Global Ensemble (TIGGE) (December planning meeting)

Current Status (Cont'd)

- Future workshops
  - Atmospheric Ensemble Applications – NCAR/2005
  - User Forum – HydroVision 2006 with AMS & CEA?
  - CHPS
  - Data Assimilation
  - Hydrologic Uncertainty – Europe?
- Connection to CEOP?

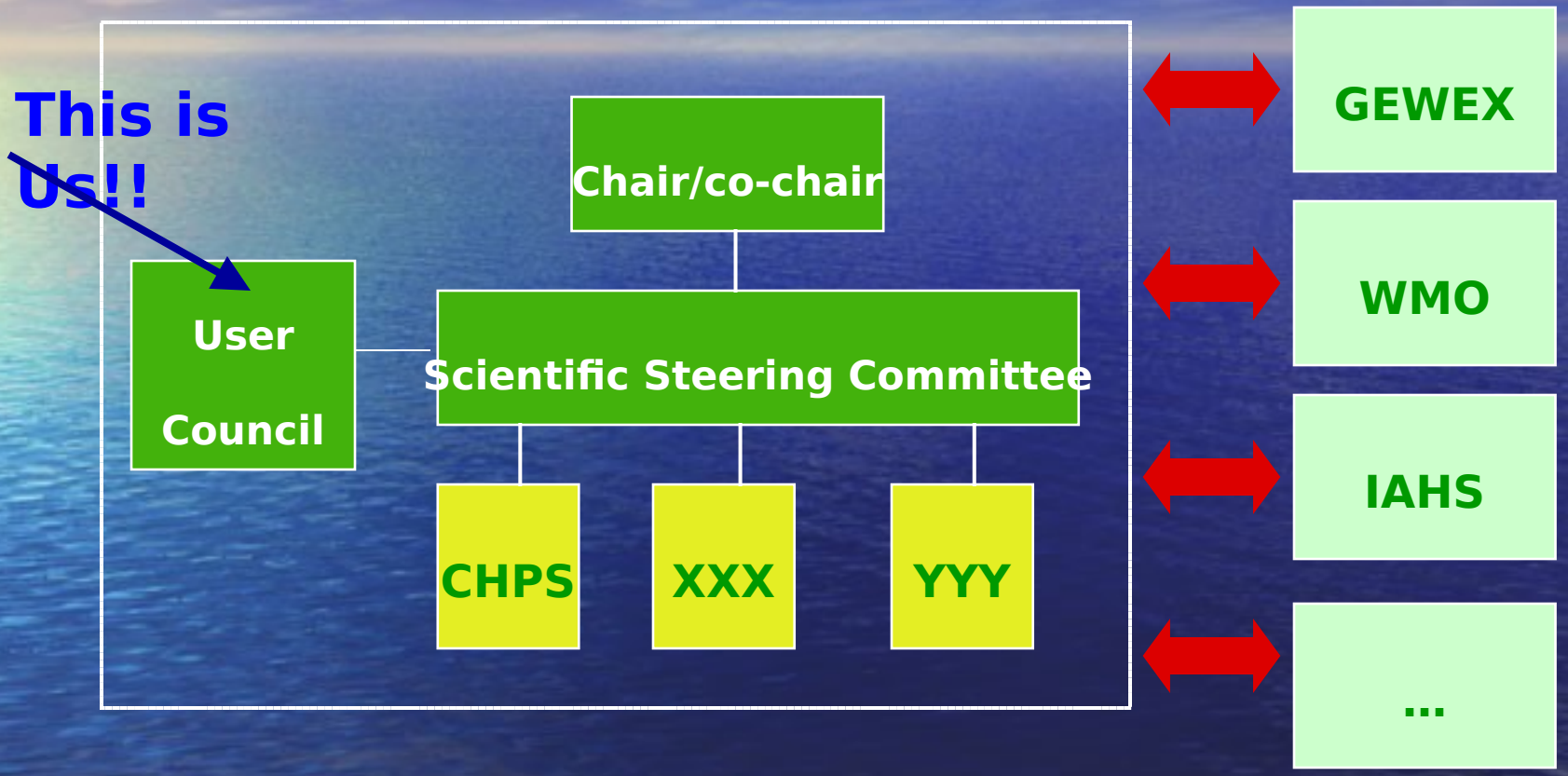
Current Status (Cont'd)

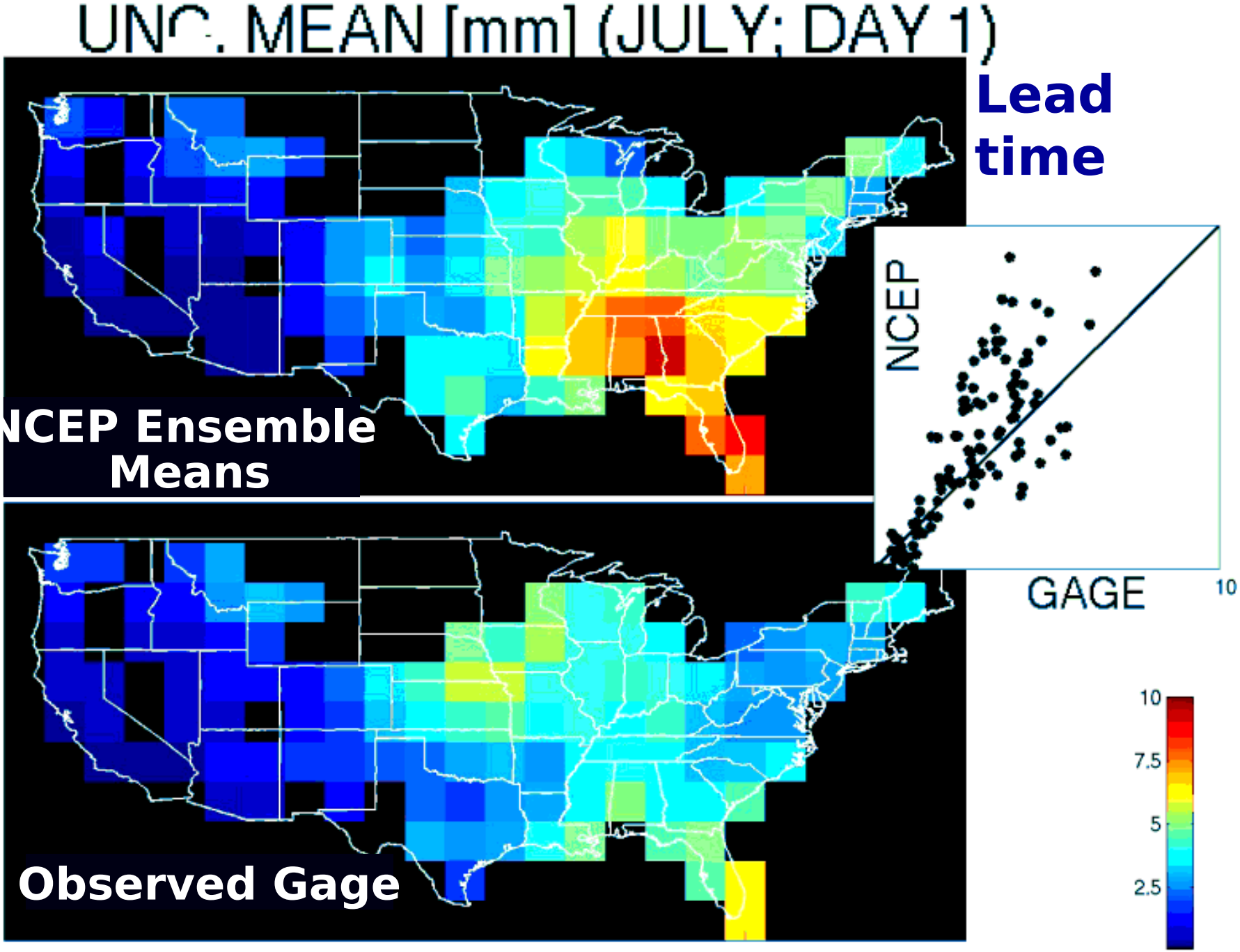
- Demonstration Projects
  - Danube (Germany, Austria)
  - EU JSC – Ispra
  - Other EU Studies (FLOODsize 10M Euros)
  - GAPP Ensemble Project (GEP)
  - 4+ RFC Pilot Studies (AHPS)
  - Canadian Project?
  - Parana/Rio de la Plata Project?
  - Australia?
  - Bangladesh/Indian monsoon (Peter Webster)?
  - Brazil Itaipu?

Affiliated Organizations

- **International**
  - GEWEX
  - WMO
  - UNESCO
  - IAHS
  - WWRP
  - ECMWF
- **National/Regional**
  - Canada Met Srvc
  - SMHI
  - BGF
  - EDF
  - Meteo France
  - Met Office
  - CEH
  - Mekorot
  - NOAA
  - NASA
  - …

Organization of HEPEX




UNC. MEAN [mm] (JULY; DAY 1)
Lead time
NCEP Ensemble Means
NCEP
GAGE
10
Observed Gage
10
7.5
5
2.5

How Good are the Ensemble Forecasts?

How Good are the Decisions Based on Ensemble Forecasts?

Ensemble Verification Statistics

Statistic	Description
Ensemble mean correlation coefficient	Correlation coefficient between the mean of the ensemble forecast and the observed value; a measure of resolution
Ensemble mean skill score	Scaled by variability in observations; a measure of resolution and reliability
Brier skill score	Can be applied to categorical events (i.e., high, medium, low); a measure of accuracy
Reliability diagram	Plot of the relative frequency of estimated non-exceedance probabilities of observations; if forecasts perfectly reliable, probabilities are uniformly distributed
Talagrand diagram	Plot of frequency of estimated non-exceedance probabilities of observations in different probability intervals; integral is consistent with the reliability diagram
Root-mean square value of deviation	Magnitude of deviation of the observed relative frequency of estimated non-exceedance probabilities from a uniform distribution; measure of reliability

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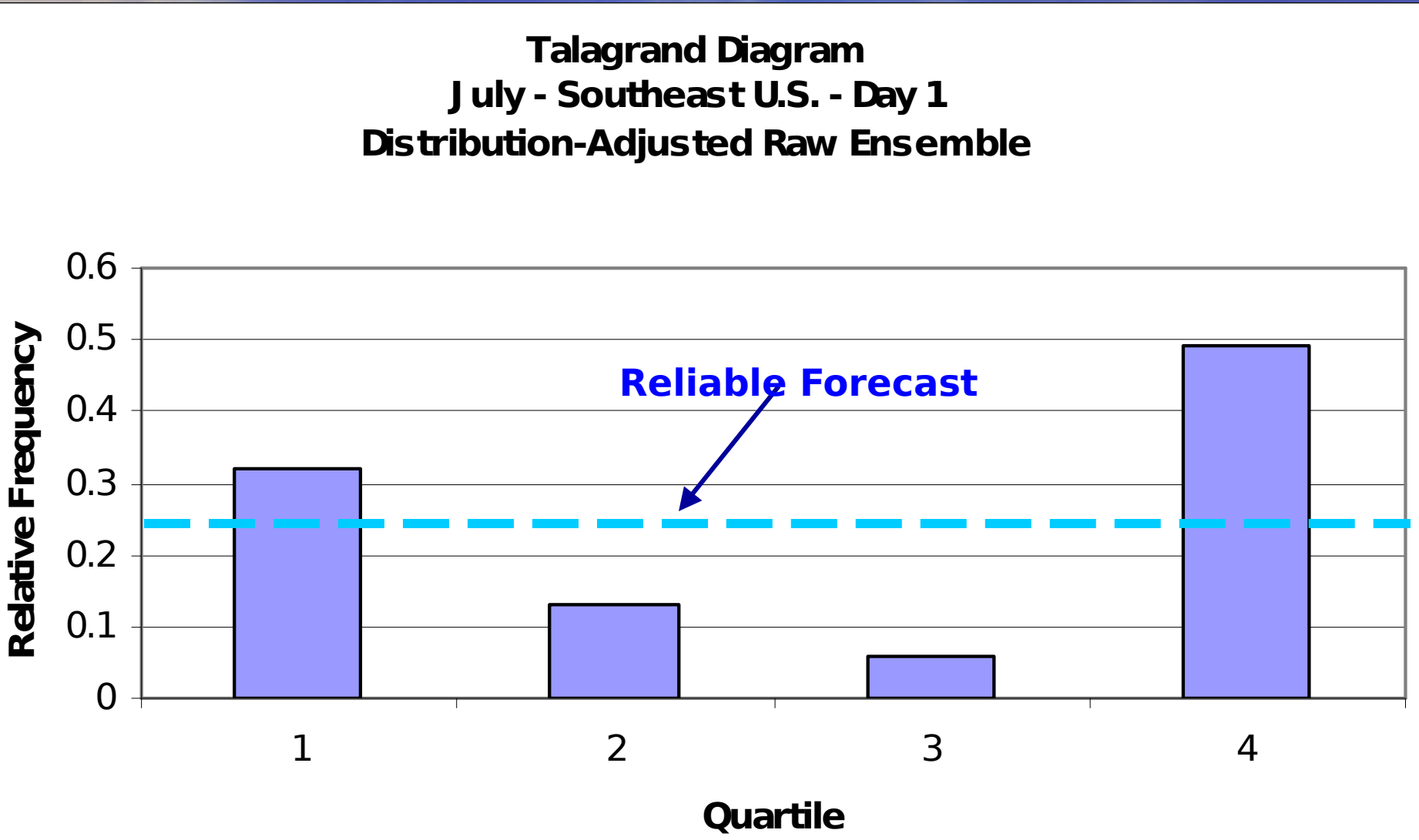
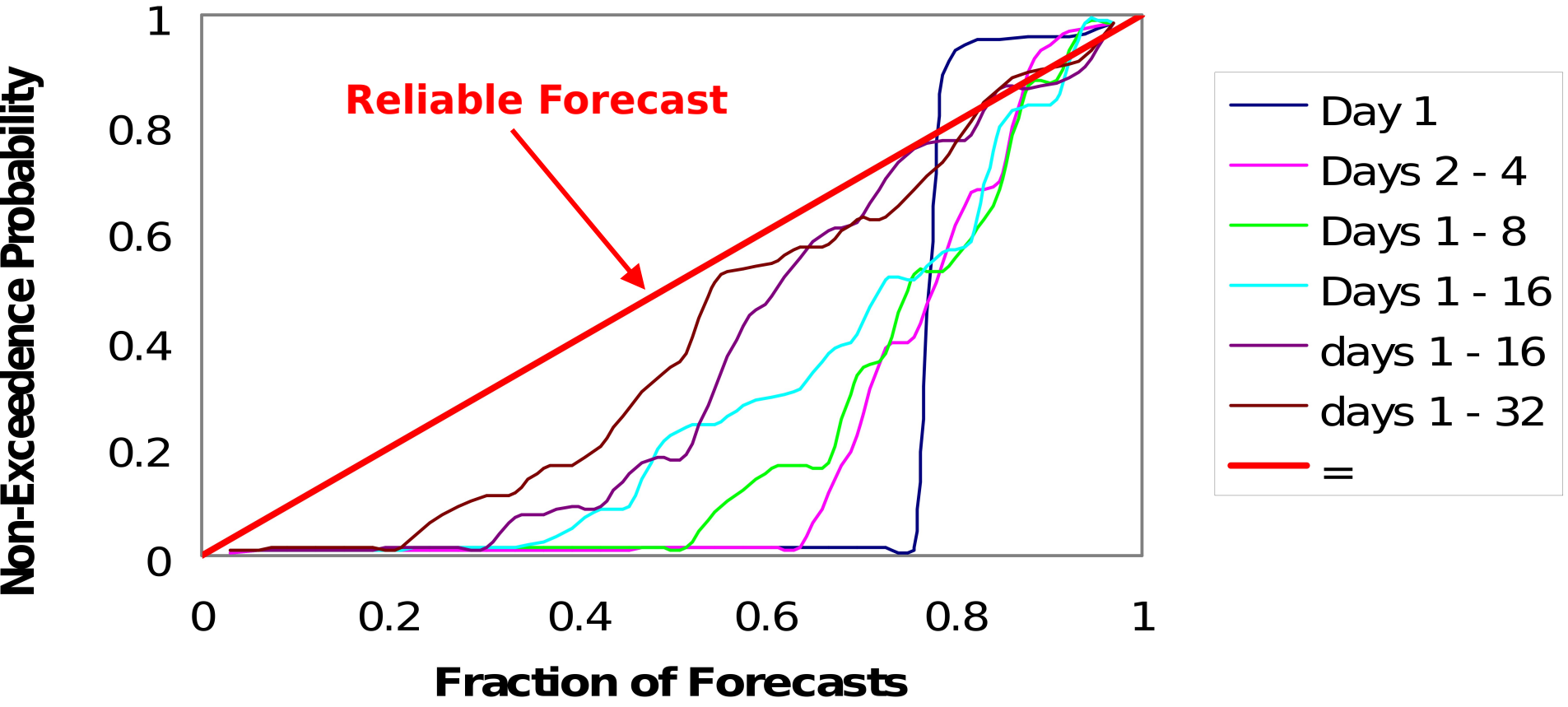
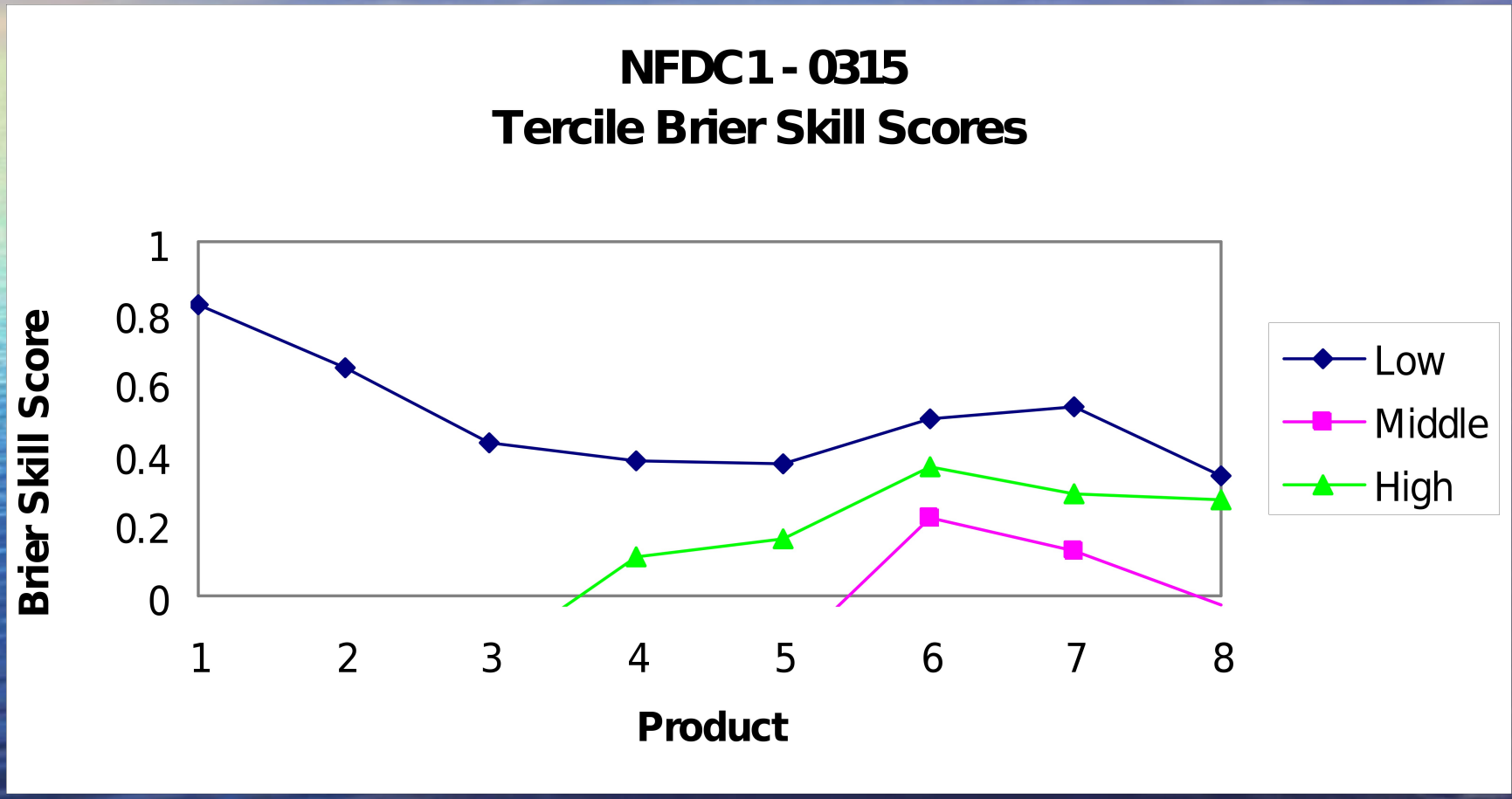
Medium Range Forecast Ensemble Spread is too Narrow



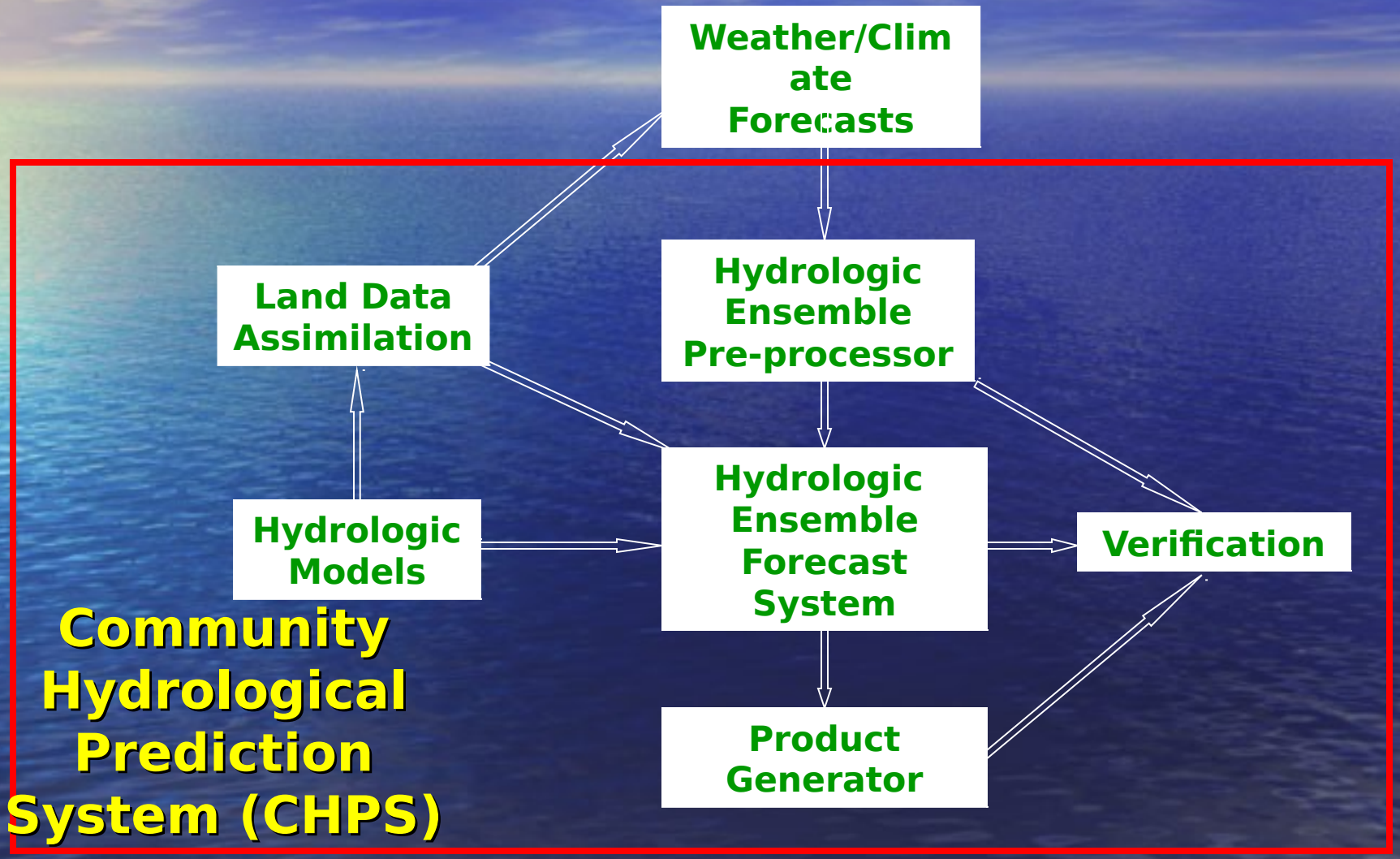
Spread of Extended Streamflow Prediction Distribution is too Narrow



ESP Probability Verification



HEPEX Components



Using Ensemble Forecasts

- **For the next two weeks**
  - **medium-range weather forecast ensembles**
- **For beyond the next two weeks**
  - **Use historical weather to go beyond weather forecasts.**

Some Research Topics

How do we integrate a Weather Forecast Ensemble with an Historical Weather Ensemble?

How do we best make use of Ensemble Weather Forecasts?

Some Research Projects

Foster collaborations with others

- **By providing ensemble weather and climate forecasts**
- **By providing techniques to make reliable weather and climate forecast ensembles out of existing operational products**

Help to support a web site that would make information available to CEA members and to the scientific community.

Potential HEPEX Contributions

- **Test-beds, Demonstration projects, Case studies, Inter-comparisons**

- **Workshops**
  - ***Meteorological Ensemble Forecasts***
  - ***Re-scaling/Downscaling***
  - ***Hydrological Ensemble Forecasts***
  - ***Modeling Hydrologic Uncertainty***
  - ***Data Assimilation***

- **CHPS (Community Hydrologic Prediction System)**
  - ***Integrate scientific contributions***
  - ***Accelerate infusion into operations***
  - ***Demonstrate achievement of HEPEX goal***

Potential HEPEX Contributions (Cont'd)

- **Education/Dissemination/Product design/Outreach**
  - ***Workshops***
  - ***Applications Case Studies***
- **Supporting Data Sets**
  - ***Ensemble Re-forecasts***
  - ***Corresponding Observations***
  - ***Others***
- **Scientific results**
  - ***EGU/AGU/AMS/IAHS/etc – Special Sessions***

Funding for HEPEX

- Funding needs to be tied to some specific purpose. Not at that point yet.
- Possible future demonstration projects
- Support for future workshops
- Support for someone to maintain a web site
- Eventually support for a HEPEX project office if we decide we should create one.

Science Steering Group

- The Steering Group will be made up of representatives nominated by the affiliated organizations.
- If CEA would like to be affiliated we would welcome that. CEA is invited to name someone to the SSG.

Science Steering Group Appointments

- Number of members?
- Selection Criteria
  - Willingness to serve and enthusiasm
  - Competence/track record
  - Geographical distribution (ideally we want HEPEX to cover the whole globe)
  - Sector expertise (ideally, we want some from different areas of meteorology, hydrology and practical applications)
  - Role in pilot projects
  - Proposed contribution

SSG Appointments

- Under the SSG and User's Council, there will be a few panels to oversee the main structural components of HEPEX as well as the demonstration projects, CHPS (Community Hydrologic Prediction System) and verification procedures.

- If anyone from CEA wants to participate in some way they would be welcome to become a panel member. I'd be glad to help make that happen.

Scientific Steering Group Candidates

- Peter Webster
- Upmanu Lau
- Ezio Todini, from Univ of Bologna
- Paolo Reggiani, from WL-Delft
- Tom Hamill (NCAR)
- Steve Mullen (AZ Univ)
- Wolfgang Grabs (WMO)
- Gabor Baling, VITUKI
- Pierre Bernard, EDF
- Brian Golding, UK Met Office
- Ken Mylne, UK Met Office
- Chiara Marsigli, ERSA-SMR Bologna (other from that group)
- Pedro Viterbo, Anna Ghelli (or Francois Lalaurette, ECMWF
- Roberto Buizza (ECMWF)
- Ad de Roo, Jutta Thielen or Ben Gouweleeuw from JRC
- Eric Wood (Princeton Univ)

- Christa Peters-Lidard (NASA)
- Efi Foufoula
- Praveen Kumar
- Alan Hall (Australia)
- Jose Marengo (Brazil)
- Marcos Prado (Itaipu Brazil)
- Zoltan Toth (NCEP)
- Ken Mitchell (NCEP)
- Chuck Howard
- Peter Krahe (BFG, Germany)
- Alan Bradley (Iowa Inst Hyd.)
- Martyn Clark
- Andy Wood
- Pedro Restrepo (CHPS)
- Bob Moore (CEH/JCHR)
- John Schaake (NOAA)

HEPEX Goal

- **HEPEX aims to** demonstrate how to produce reliable hydrological ensemble forecasts that can be used with confidence to make decisions for emergency management and water resources management.

This will have important consequences for the economy, for public health and safety.

Thank you for your attention
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